

# Forest landscape dynamics in the cotton basin of North Benin

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**Abstract**—The agro-ecological zone of the cotton basin of North Benin is a rainfed cereal farming area. In addition, the area is one of the country's favourable Cotton growing areas, which affects the configuration of its landscape. This study analyses the dynamics of the forest landscape in the cotton basin of North Benin between 1986 and 2000. A multidimensional approach was used based on a participatory inventory, field observations and statistical analyses of data from the interpretation of SPOT images. Several indices were calculated, including the importance value of the degree of disturbance, the composition and spatial configuration indices of the landscape types. Then, the sample test matched to the 5% threshold of the disturbance levels obtained between 1986 and 2000 on the one hand and between 2000 and 2016 on the other hand to ensure their significance. The results of this study show two types of disturbance, namely natural (4) and anthropogenic (7). Analysis of these disturbances also shows that agriculture (IV = 0.97), overgrazing (IV = 0.88), timber and service harvesting (IV = 0.78) and carbonization (IV = 0.63) are the main human disturbances in the study area. In addition, there is rapid population growth (IV = 0.94) and climate disturbances (IV = 0.85). In addition, the forest landscape has seen an increase in the number of spots (from 666 in 1986 to 2419 in 2016) and a decrease in the total area. Similarly, the values of the contagion index, ranging from 82.32 in 1986 to 65.82 in 2016, reflect a very fragmented landscape. Thus, the fragmentation of the forest landscape in the cotton basin of North Benin raises, in a very particular way, the problem of the conservation of plant biodiversity.

**Keywords**—Current disturbances; forest landscape; dynamics; cotton basin; North Benin.

## I. INTRODUCTION

In the natural environment, the dynamics of forest ecosystems are strongly affected by the disturbance regime. These disturbances are discrete events over time and often unpredictable, acting at all spatial scales [1]; [2]. They can be of various natures (natural or anthropogenic), punctual (logging) or quasi-permanent [3]. Indeed, in their natural functioning, plant communities are perpetually subjected to various constraints and disturbances [4]; [5] leading to changes in plant succession and environmental degradation [6] and consequently to the loss of habitats and species [7].

In northern Benin, agriculture is perceived as the main driving force behind the change in vegetation cover in the region [8]; [9].

In the agro-ecological zone of the cotton basin of North Benin, cotton is the most important agricultural practice that forces farmers to clear several hectares each year [10]; [11]. In addition, current cotton production techniques characterized by slash-and-burn agriculture,

harness farming, the use of agricultural machinery and the high use of insecticides and pesticides [12] on plots increase the frequency and intensity of disturbances. Thus, understanding observations of landscape change in the study area is crucial due to interactions with farmers [13]. The direct consequence of these disturbances is the fragmentation of ecological systems in this very perceptible area, thus creating the problem of the sustainability of natural biocenoses and the maintenance of plant biological diversity [12].

Faced with this ecological imbalance caused by disturbances, it is still necessary to identify and analyze the types of disturbances and understand their influences on vegetation [7]. In addition, quantification of the spatial structure of the landscape and the knowledge of local populations make it possible to measure the effect of changes in disturbance patterns and the level of plant resources available as a result of the intensification of agricultural practices in the cotton basin. The objective of this study is to analyze the current types of

disturbances and their relationship to the dynamics of the forest landscape in the cotton basin of North Benin.

## II. STUDY AREAGS

Benin's cotton basin is located in the Sudanese region of Benin with an annual rainfall of 800 to 1100 mm, an average temperature of 24 to 31 °C, an exposure of 2862 hours/year, a relative humidity of 18 to 99%, a dry Sudanese climate [14], a vegetation consisting mainly of savannah and gallery forests for lithosols and hydromorphic soils [15]; [16]; [13]. It covers an area of 3127.87 km<sup>2</sup>. It is located in the Alibori department, between 2°12 and 2°55 east longitude and between 10°42 and 11°15 north latitude and is located in the town of Banikoara (north), Gogounou (south), Kandi (east) and Kérou (west) (Fig. 1).

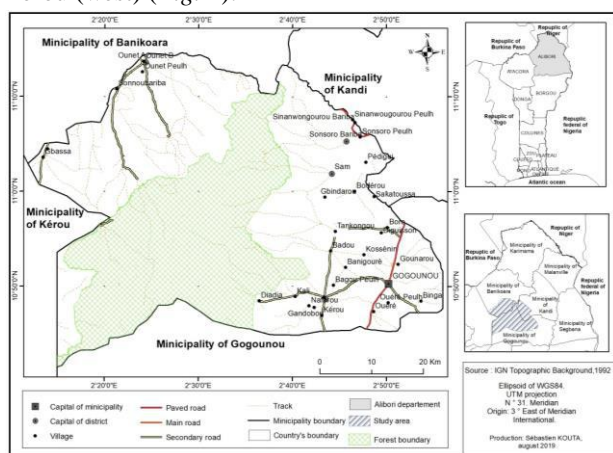


Fig. 1: Location of the study area

## III. MATERIALS AND METHODS

In this study, the classified SPOT images of the year 1986, year 2000 and year 2016 of the study area were used to quantify the spatial heterogeneity of the forest landscape and the main disturbances responsible for this heterogeneity in the North Benin cotton basin.

The types of disturbances were identified through a focus group participatory inventory carried out with 293 people, these data were validated by field work. Several indicators (social, economic and ecological/environmental) were discussed with the various stakeholders. Open interviews with them made it possible to describe the main disruptions in the study area (Table 1).

Table 1: Degree of disturbance and their characteristics

Degrees of disturbance	Description	landscape Units
Very high	Continuous exploitation	Crops and fallows
High	Conversion of forest units into	Forest in cultivation and

	anthropized units	fallow
Low	First-order or second-order degradation of forest units	Forest unit to forest unit
Negligible	Confirmation of the forest unit	Same forest unit

### 3.1 Statistical analysis of data

To assess the different disturbances in the cotton basin of North Benin, the significance value (IV) was used. This parameter calculates the proportion of respondents who consider an activity or factor to be a landscape disturbance [17]. It varies from 0 to 1 and is determined by the following formula:

$$IV = \text{nis} / n (1)$$

With nis is the number of respondents who consider an activity or factor to be a landscape disturbance and n the total number of respondents.

To better analyze these disturbances according to different actors, a simple correspondence analysis (SCA) was performed with MINITAB 17.0 software. In addition, the same software was used for the sample test matched to the 5% threshold of the disturbance levels obtained between 1986 and 2000 on the one hand and between 2000 and 2016 on the other hand to ensure their significance.

### 3.2 Quantification of forest landscape dynamics

Spatial heterogeneity reflects the complexity and variability of a system's properties over time and space [18]; [19]; [20]. Several indices evaluating the composition and configuration of the landscape were calculated. The composition indices consist of: number of tasks (NP) which measures the number of habitat units of a given class; the average area of a spot (Area Mean) calculates the area of a habitat unit belonging to a given class. The Largest Patch Index (LPI) measures the percentage of landscape occupied by the largest habitat unit in a given class. The Patch Density Index (PD) partly solves this problem by calculating the number of habitat units of a given class per area unit.

#### 3.2.1 Shannon Diversity Index (SHDI)

SHDI measures the heterogeneity of the landscape (bits) combining richness and regularity. A value of this index equal to 0 indicates a homogeneous landscape [21]. It is given by the following formula:

$$SHDI = (-\sum (p_i * \ln(p_i))) (2)$$

$p_i$  = total number of cells in category  $i$  / total number of cells in the landscape (1). This index is more sensitive than the Simpson index to rare patches.

#### 3.2.2 Simpson Diversity Index

This index is used to quantify the distribution of abundances between the different categories [21]; [22]. It is given by the following formula:

$$SIDI = 1 - \sum p_i^2 \quad (3)$$

With  $p_i$  = total number of cells in category  $i$  / total number of cells in the landscape.

A value of 0 in this index indicates that there is only one spot, a value of 1 indicates that the landscape is composed of many nearby abundance spots. SIDI can be interpreted as the probability that two random cells are of different categories.

### 3.2.3 Total Landscape Percentage (LPI)

LPI measures the area (%) of the largest task for each landscape unit [22]. The high LPI values indicate a strong dominance of a single stain.

$$LPI = \frac{\max(a_{ij})}{A} (100) \quad (4)$$

$a$  = area ( $m^2$ ) of patch  $ij$ .  $A$  = total landscape area ( $m^2$ ).

### 3.2.4 Contagion index (CONTAG)

The contagion index [22] measures the degree of adjacency of the pixels of a raster. It is given by the following formula.

$$CONTAG = \left[ 1 + \frac{\sum_{i=1}^m \sum_{k=1}^m \left[ p_i \cdot \frac{g_{ik}}{\sum_{k=1}^m g_{ik}} \right] \cdot \ln \left( p_i \cdot \frac{g_{ik}}{\sum_{k=1}^m g_{ik}} \right) \right]}{2 \ln(m)} \right] \quad (5)$$

$P_i$  = proportion of the landscape occupied by the patch type (class)  $i$ ;  $ik g$  = number of adjacencies (joints) between the pixels of the patch types (classes)  $i$  and  $k$  according to the double counting method and  $m$  = number of patch types (classes) present in the landscape, including the edge of the landscape if present.

The index values vary from 0 to 100; high values reflect the grouping of pixels in the same class, low values reflect the dispersion of pixels in the same class.

### 3.2.5 Patch Density (PD)

PD is the number of plots of the corresponding plot type divided by the total area of the landscape ( $m$ ), multiplied by 10,000 and 100 (to be converted into 100 hectares).

$$PD = ni/A \times (10000) \times 100 \quad (6) \quad [22]$$

$ni$  = number of patches in the landscape of patch type (class)  $i$  and  $A$  = total area of the landscape ( $m^2$ ).

Note: the total area of the landscape ( $A$ ) includes any internal backgrounds present. In addition, the number of patches and the average patch area were calculated.

All these indices were generated using Fragstats software [23]. This software allows you to work from the

interpretation of land cover in ASCII or raster format. However, a preliminary configuration work must therefore be carried out before the clues of this software can be requested. All these analyses were performed on SPOT 1, SPOT 4 and SPOT 7 images classified in raster mode.

## IV. RESULTS

### 4.1 Typology of disturbances in the cotton basin of North Benin

The government's willingness to invest in cotton production creates continuous pressure on the natural vegetation of the cotton basin in northern Benin. In total, seven types of disturbances were identified. Fig. 2 shows the different types of disturbance according to their importance.

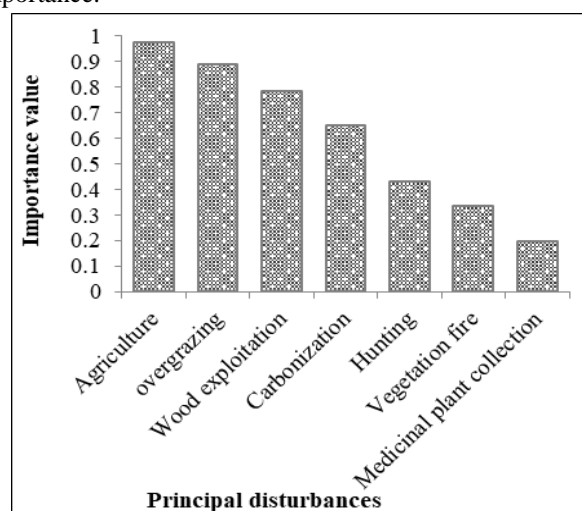


Fig. 2: Importance of current disruptions in the study area

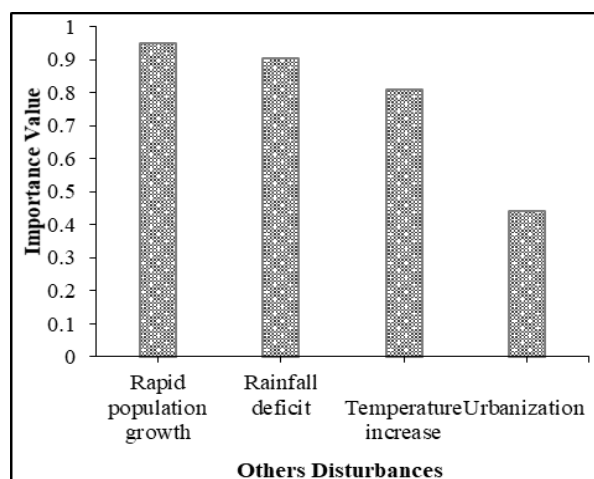


Fig. 3: Importance of current disruptions in the study area

The examination of Fig. 2 shows that the main disruptions in the cotton basin of North Benin are

agriculture (IV = 0.97), overgrazing (IV = 0.88), timber and service harvesting (IV = 0.78) and carbonization (IV = 0.63). Hunting, wildfires and the collection of medicinal plants have been observed but with a low value. In addition to the main disturbances in the study area, there are also other disturbances such as rapid population growth (IV = 0.95); climate disturbances including rainfall deficits (IV = 0.90) and temperature increase (IV = 0.81) and urbanization (IV = 0.45) (Fig. 3).

#### 4.1.1 Spatialization of disturbance levels in the cotton basin of North Benin

The Fig. 3 shows the map of the degree of disturbance in the cotton basin of North Benin.

The analysis in Figure 3 shows that between 1986 and 2000 (P1), a much more negligible degree of disturbance was observed. This means that the same forest units were confirmed at 39%. They are observed to the northwest and within the classified forest of the Upper Alibori. In addition, there are high (14%) and very high (12%) disturbances to the northeast and southeast of the study area. Minor disturbances (35%) in the landscape are observed throughout the study area. The same trend can be observed between 2000 and 2016 (P2) but with a decrease in negligible (37%) and low (6%) disturbances and an increase in high (32%) and very high (25.30%) disturbances. Thus, the landscape of the cotton basin of North Benin is more disturbed during the second period (2000 to 2016), i.e. 16 years of landscape modification.

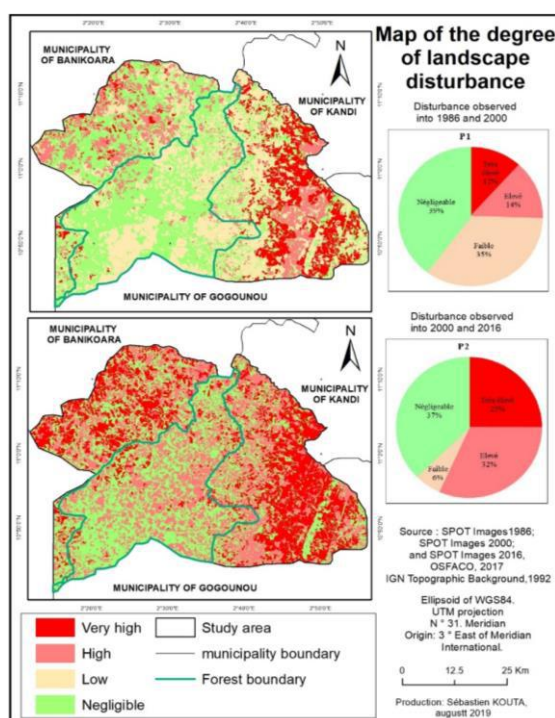


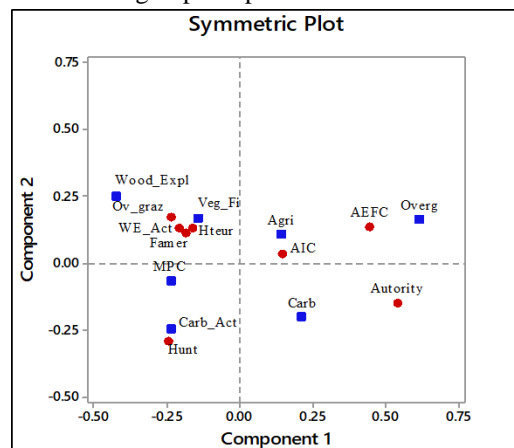
Fig. 3: Degree of disturbance in the cotton basin of North Benin

#### 4.1.2 Comparison of the degree of disturbance between P1 and P2 (1986 to 2000 and 2000 to 2016)

The results of the Wilcoxon t-test of the paired sample at the 5% threshold show an insignificant difference between the degree of disturbance of the two periods (P1 and P2) ( $p = 1,000$ ). This means that the different degrees of disturbance follow the same distribution law.

#### 4.1.3 Local people's perception of the extent of disturbance

The Fig. 4 show the perception of local populations on the current disturbances in the cotton basin of North Benin according to principal actors.



Legend: Ag = Agriculture; Overg = Overgrazing; Ov\_gaz = pastoralists; Wood\_Expl = Wood exploitation; WE\_Act = Wood exploitation actors; Car = Carbonization; Carb\_Act = charcoal producers; Veg\_Fi = Vegetation fire; MPC = Medicinal plant collection; Hter = Hunters; Hunt = Hunting elected officials; AEFC = Water, forest and hunting officers and AIC = Interprofessional Cotton Association

Fig. 4: Local people's perceptions of current disturbances

Agriculture, overgrazing, timber and service harvesting and carbonization are the main ecosystem disruptions in the cotton basin (Figure 4). However, each category of actors has brought nuances in a particular way. In axis 1, the Water, Forestry and Hunting Officers (AEFC) and the Interprofessional Cotton Association (AIC) consider that the main factors of ecosystem degradation in the study sector are agriculture and overgrazing. For the latter, the degree of ecosystem disruption through medicinal plant collection and forestry exploitation is low. On axis 2, pastoralists, farmers, foresters, hunters and local elected officials believe that the main disturbance is natural. This disturbance is limited to wildfires. On the other hand, charcoal producers see hunting and carbonization as disturbances to the forest landscape in the cotton basin of northern Benin.

#### 4.2 Quantitative analysis of forest landscape dynamics in the cotton basin

##### 4.2.1 Composition indices

The results of the various indices are shown in Table 2.



Table 2: Evolution of landscape composition indices between 1986 and 2016

Indice	Year 1986	Year 2000	Year 2016
Number of Patch	666	1232	2419
Patch Density	0.21	0.39	0.77
Largest Patch Index (%)	87.09	67.77	31.83
AREA_MN (ha)	469.30	253.78	129.21

From the examination of Table 2, it appears that the number and density of spots and the landscape shape index increase with time (1986 to 2016). This shows that the forest landscape in the study area is changing. On the other hand, the Largest Patch Index and the average stain area decreased from 1986 to 2016. This shows that the largest landscape unit was observed in 1986 with an average area of 469.30 ha. This unit will experience a reduction in its surface area in 2000 (253.78 ha) and then in 2016 (129.21 ha).

#### 4.2.2 Shannon and Simpson Diversity Index

To quantify the distribution of abundance among the different landscape units, two indices were calculated, including the Shannon and Simpson diversity index (Fig.5).

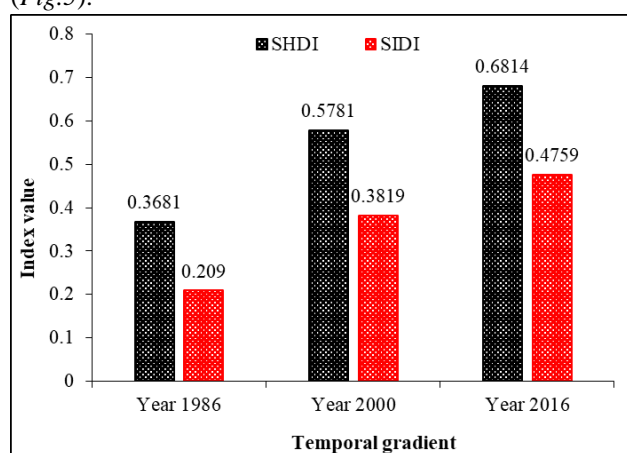


Fig. 5: Shannon and Simpson diversity indices between 1986 and 2016

The analysis in Fig. 5 shows that the calculated diversity indices evolve increasingly according to the temporal gradient. Indeed, Shannon's diversity index increased from 0.37 bits (1986) to 0.68 bits (2016) while Simpson's index varied from 0.209 (1986) to 0.476 (2016). This increasing evolution of these indices indicates that the landscape is composed of many close and heterogeneous abundance spots.

#### 4.2.3 Landscape shape index

Relationship between surface area and perimeters of landscape units

The analysis of the ratio between the surface and the perimeter makes it possible to quantify the complexity of the landscape units. The Fig. 6 shows the evolution of this ratio between 1986 and 2016.

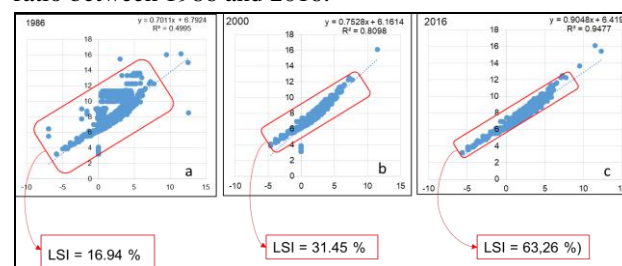


Fig. 6: Evolution of the ratio between the area and the perimeter of landscape units

The Fig. 6 shows that in 1986 (Fig. 6a), the shapes of these units have few edges and large core areas, while in 2000 (Fig. 6b) and 2016 (Fig. 6c), the shapes of these same units are elongated and have more edges but small core areas. This reflects the fragmentation of landscape units in the cotton basin of North Benin. This landscape fragmentation is confirmed by the values of the landscape shape index which increases with the time gradient. In 1986, this index gave an LSI value = 16.94%; in 2000, LSI = 31.45% and in 2016, the value of this index was three times higher than that obtained in 1986 (LSI = 63.26%).

#### 4.2.4 Configuration indices

Configuration indices measure the degree of connectivity or isolation between habitat units in a landscape. The configuration index used in this study is based on the contagion index (Fig. 7).

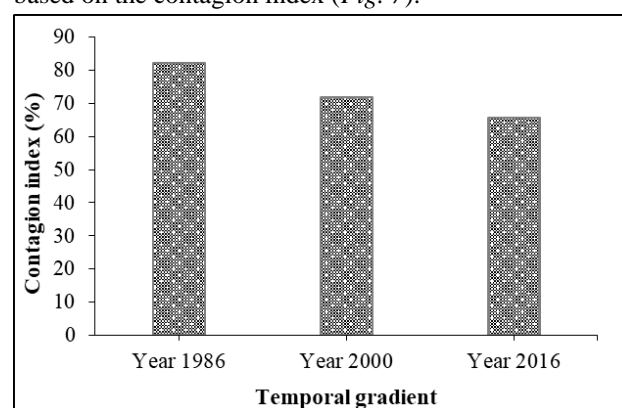


Fig. 7: Evolution of the contagion index between 1986 and 2016

The values of the contagion index, ranging from 82.32 in 1986 to 65.82 in 2016, reflect a very fragmented landscape.

## V. DISCUSSION

### 5.1 Analysis of current disturbances in the cotton basin of North Benin

In the agro-ecological zone of the cotton basin of North Benin, wildfires, landscape fragmentation due to the opening of agricultural land (cotton cultivation), exploitation of timber and service wood, firewood collection, charcoal production and grazing under forest cover are the main disturbances leading to a dynamic vegetation cover. One of the main causes of these disturbances is the monoculture of cotton and the selective cutting of commercially valuable woody species. Thus, the landscape is disturbed by the gradual increase in agricultural land due to cotton production [13]. These current disturbances show the evolution, degradation and deforestation of the forest landscape in the cotton basin of North Benin. Urbanization with the road network and other accompanying infrastructure, initially negligible, then increases. Similarly, selective logging intensifies over time to become the main disturbance. Fires increase and then decrease when the front is consolidated. In the cotton basin of northern Benin, slash-and-burn shifting cultivation, dominated by cotton monoculture, has influenced vegetation succession processes, leading to the loss of plant biodiversity. Livestock overgrazing is increasing, particularly due to the fragmentation of the forest in the study area. In the world, selective logging is responsible for half of the degradation of tropical forests, energy wood collection is responsible for a third. It is therefore important to be able to reconcile these results of landscape anthropization with the country's agricultural policy in order to achieve sustainable development [13]. [24] go in the same direction by showing that in northern Benin, agricultural activities are the major causes of land cover degradation. This theory is supported by de [25] and [26]. Several authors have also shown that disturbance regimes are the factors that mainly influence forest landscape dynamics, and are mainly determined by agricultural management practices that modify the composition of plant communities, with ultimate impacts on ecosystem functions [27]. According to [7], disturbances divide forest landscapes into fragments and this fragmentation is characterized by two major processes: the loss and spatial isolation of viable habitats.

### 5.2 Forest landscape dynamics in the cotton basin of northern Benin between 1986 and 2016

In this study, the calculated spatial structure indices are the number of spots, their density and total area, the area-perimeter ratio, the average area of tasks, the Shannon, Simpson, shape and contagion indices. The results of the indices obtained in 1986, 2000 and 2016 showed that the forest landscape has seen an increase in the number of spots (from 666 in 1986 to 2419 in 2016) and a decrease in the average area (469.30 ha in 1986 to

129.21 ha in 2016). Similarly, the values of the contagion index, ranging from 82.32 in 1986 to 65.82 in 2016, reflect a very fragmented landscape. Moreover, the increasing increase observed in the calculated Shannon and Simpson diversity indices indicates that during these different dates (1986, 2000 and 2016) the forest landscape of the cotton basin of North Benin experienced significant disturbances. These results fully confirmed those of [28], [29], [13], and [30]. In the authors' opinion, fragmentation leads to a reduction in the total area and an increase in the number of spots. They later pointed out that as the number of spots increases, large spots are fragmented, reducing their total area. This regressive dynamics of the forest landscape of the cotton basin of North Benin is caused by anthropogenic influence as seen above, resulting in its spatial heterogeneity. According to [20], most measures of heterogeneity are not spatially explicit but are spatially important. This conclusion is reinforced by [18] and [19] by showing that spatial heterogeneity reflects the complexity and variability of a system's properties over time and space.

## VI. CONCLUSION

Disturbances, in general, cause vegetation fragmentation to the detriment of native species and the well-being of the local population. These current disturbances are the source of the dynamics of forest landscapes, creating their spatial and temporal heterogeneity. This study has shown that the degree of disturbance in the cotton basin of North Benin has led to the fragmentation of the forest landscape into much smaller, more isolated fragments. It is a landscape subject to a strong anthropization. These results have implications for policy making and land management in the study area where populations are increasing and where agriculture is intensifying

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